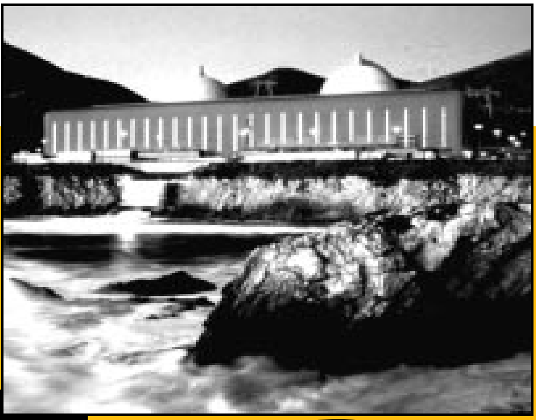
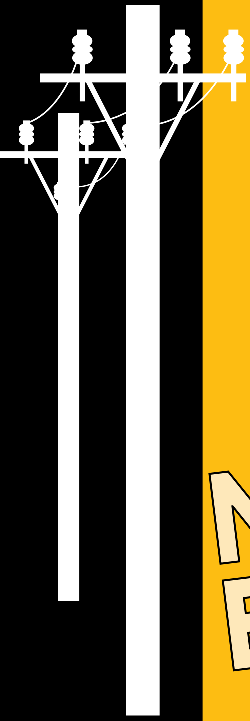
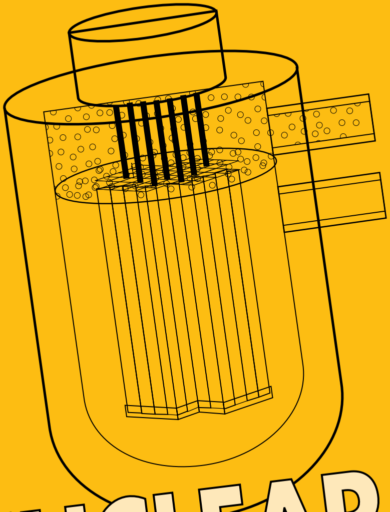
DOE/NE-0069

NUCLEAR POWERPLANT SAFETY:

Design and Planning







NUCLEAR ENERGY

U.S. Department of Energy
Office of Nuclear Energy, Science, and Technology

On the cover:
Diablo Canyon
Nuclear Reactor,
California

Nuclear Powerplant Safety: Design and Planning

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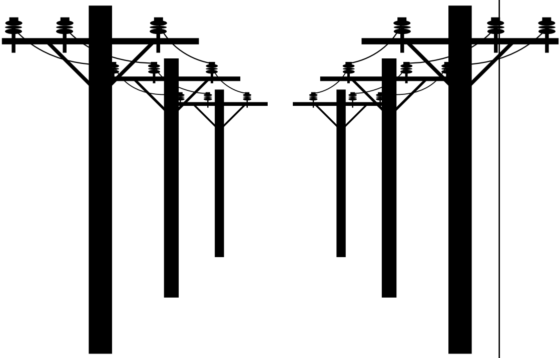
U.S. Department of Energy
Office of Nuclear Energy,
Science, and Technology
Washington, D.C. 20585

Nuclear Powerplant Safety: Design and Planning

Safety in our nation's nuclear energy powerplants is no accident. Careful planning, good engineering and design, strict licensing and regulation, intensive training of operators, and thorough environmental monitoring help to ensure that nuclear powerplants operate safely.



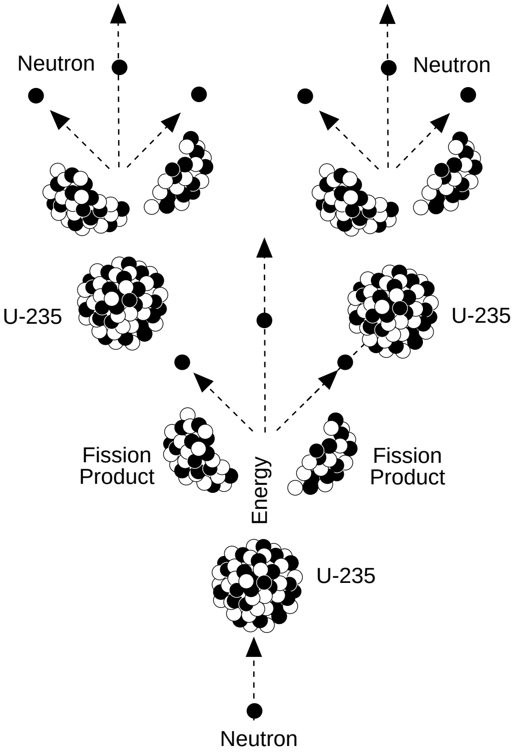
Powerplants that make electricity from nuclear energy are not very different from other kinds of power-producing plants. First, water is heated and becomes steam. The high-pressure steam turns the blades of a turbine, which spins the shaft of a huge generator. Inside the generator, coils of wire and magnetic fields interact to create electricity.

The main difference is that in conventional powerplants, the water is heated by fossil fuels such as coal, natural gas, or oil. In nuclear powerplants, the water is heated by the energy from a process called nuclear fission.

Energy in Action

As shown below, when a high-energy neutron strikes the nucleus of an atom of uranium (U-235), the uranium atom will split apart, or fisson. Uranium-235 is the form (or isotope) of uranium which undergoes fisson most efficiently. When an atom of U-235 fissions, it releases a great amount of energy, as well as more neutrons which in turn strike other atoms. This process of one fission response triggering others and those triggering still others is called a chain reaction.

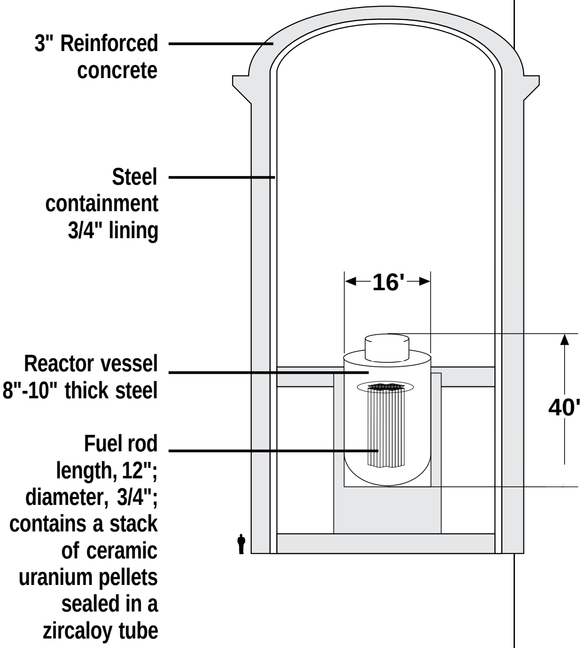
The uranium that is used in a nuclear reactor is shaped into hard pellets about the size of the end of your finger. These fuel pellets are stacked end-to-end in 12-foot long tubes made of zirconium, a metal alloy. Bundles of fuel rods make up fuel assemblies, and groups of fuel assemblies form the nuclear reactor core.



To control the nuclear chain reaction, some rods in the reactor contain materials that absorb neutrons and prevent them from hitting atoms and causing more fission. The nuclear reaction can be increased or slowed down by varying how many of these control rods are withdrawn, and how far. If the control rods are inserted completely into the core, the fisson reaction stops. Water flowing up through the fuel assemblies and control rods removes the heat of the chain reaction.

Containing the Radiation

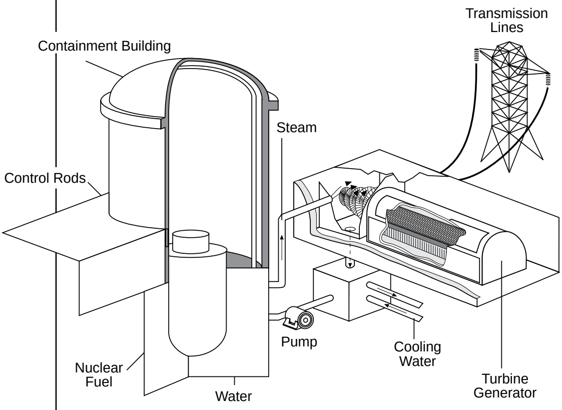
Ionizing radiation, like x-rays or the radiation produced by a nuclear chain reaction, must be carefully contained and controlled. Nuclear powerplants have many protective barriers designed to prevent a release of radioactive materials.



The first barrier is the form of the fuel itself. When it is made into reactor fuel, uranium is compressed into extremely hard ceramic pellets which will not dissolve or melt, even at temperatures above 2,000° F. This is much hotter than the reactor core's operating temperature. The radioactive by-products of fission remain locked inside the pellets.

As a second barrier, the fuel pellets are contained inside rods made of zirconium. Zirconium is a metal alloy which resists radiation, heat, and corrosion.

A massive steel pressure vessel around the reactor core is the third barrier. A typical vessel weighs more than 500 tons and has a 9-inch thick wall of carbon steel lined with stainless steel.



The final barrier to a release of radioactive materials is a robust containment structure. This structure is made of steel-reinforced concrete, with walls up to three or more feet thick. The Nuclear Regulatory Commission (NRC) requires that the containment structure for a nuclear powerplant be capable of withstanding severe outside events such as an earthquake, a tornado, or the impact of a large aircraft.

Safety by Design

Nuclear powerplants are designed to withstand a combination of extreme and highly unlikely events. Numerous safety systems help to prevent reactor accidents and to minimize the effects if an accident were to occur, due to equipment failure, human error, or a natural disaster. For example, safety systems come on as soon as the temperature in the reactor rises above normal levels. All crucial safety systems have backups.

Nuclear powerplants have systems that shut down the reactor when monitoring instruments find a problem. Leak detection equipment lets operators know any time the cooling system fails. In addition to the main cooling system, reactors have separate and independent emergency cooling systems, which automatically come on when safety sensors detect a loss of coolant. In case of a power failure, backup generators provide power to operate cooling pumps and emergency equipment.

Finally, the multiple barriers included in the reactor design help to prevent radioactive materials from escaping the plant if there were an accident in the core.

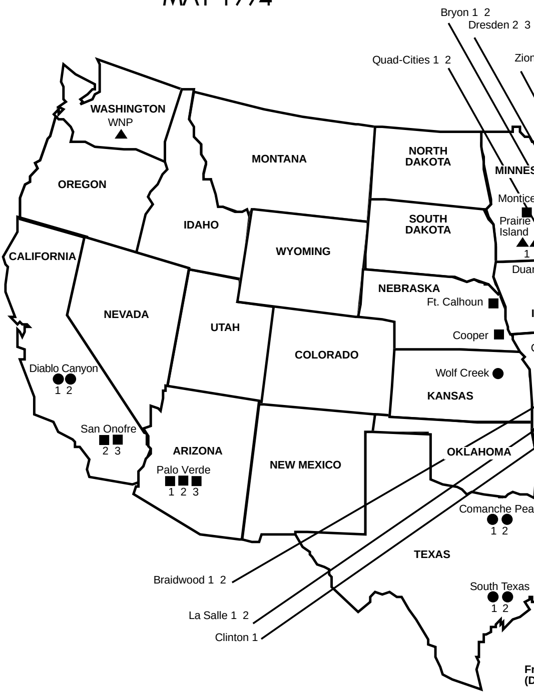
Storing Spent Fuel

Approximately every 18 months of operation, part of the fuel from the reactor core needs to be replaced with new fuel. The used, or spent, fuel is sometimes referred to as high-level waste because it is still radioactive, even though the fisson reaction has stopped.

The spent fuel assemblies are removed from the core and transferred to deep, steel-lined, concrete pools. The water in the pool cools the fuel and also acts as a radiation shield.

Although the present method of storing spent fuel has been proven safe, available storage space is filling up. The Department of Energy (DOE) is working closely with industry to find the best solution to this problem. Using existing technology, it is possible to design, construct, and safely operate a high-level waste repository. The DOE is currently studying Yucca Mountain in Nevada to

COMMERCIAL NUCLEAR POWER REACTORS IN THE UNITED STATES MAY 1994



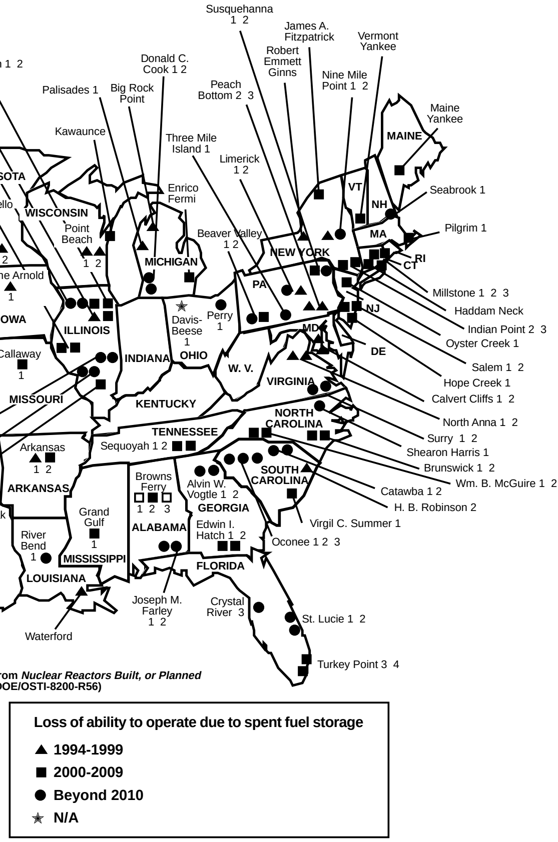
NUCLEAR GENERATING UNIT PROFILE		
Status	No. of units	Capacity net MW(e)
n Full-power license	107	96,630*
n Shutdown under review	2	2,130**

* Maximum dependable capacity ** Design electrical rating

determine whether it is a suitable location for permanent storage of this high-level waste.

Three Mile Island

Unit 2 at the Three Mile Island Nuclear Powerplant near Harrisburg, Pennsylvania, had a loss-of-coolant accident in March 1979. Experts today agree that while the event itself was minor, the ensuing mechanical problems



rom *Nuclear Reactors Built, or Planned*
DOE/OSTI-8200-R56)

and human error contributed to the consequences of the accident and made it much more serious.

The gauges that plant operators relied upon malfunctioned and incorrectly showed that the reactor was filling up with water. In reality, the core was losing coolant because a relief valve apparently stuck open and remained open for over two hours. In the meantime, the operators misinterpreted the information given by their instruments and decided to turn off the cooling pumps. As a result, the temperature in the core rose, and some fuel assemblies experienced some amount of melting. There was a large release of radioactive material into the containment building, but only a very small amount of radioactivity made its way into the environment outside the plant. People living within 10 miles of the plant received, on average, about the same amount of radiation as you would get from a chest x-ray.

Although the accident at Three Mile Island was the worst in U.S. commercial nuclear powerplant operations, the safety systems, the operators, and the barriers ultimately functioned properly. Most importantly, no plant personnel or members of the public received any physical injuries from the accident.

The Three Mile Island accident was a catalyst for change within the nuclear industry, which led to a review of nuclear powerplant design, safety, and emergency planning. Studies of the accident by various groups, including the presidentially appointed Kemeny Commission, the Nuclear Regulatory Commission (NRC), and Congressional groups, resulted in many improvements.

These changes include:

- Plant design improvements to prevent a recurrence of the events that led to the accident.
- Direct communication lines between the control room, the NRC, and reactor designers.
- More and better instruments in the control room to give operators information on conditions at a glance.
- Changes in control room layout to improve operators' understanding of the reactor's condition.
- Establishment of three separate centers at each facility to report plant status, coordinate personnel, and support reactor operators.
- Improved operator training.
- Creation of the Institute of Nuclear Power Operations (INPO), which evaluates operating practices at all nuclear powerplants.

Safety through Planning

The siting and construction of a nuclear powerplant involves extensive planning and review, including site assessments, management reviews, surveillance, and other measures to keep the plants safe. The NRC took a giant step in April 1989, when it issued new licensing rules that allow these assessments to be completed and plant sites and designs to be approved before construction begins and billions of dollars are at risk. The Energy Policy Act of 1992 contains licensing reform provisions that require public hearings when a plant design is certified, when a site permit is issued, and when a utility seeks a construction/operating license. The bill ensures full public participation in key safety and design decisions before a plant can be built, when public input can be most effective.

Choosing a site for a nuclear powerplant depends on several factors, such as:

- size of the site
- stability of the land
- weather patterns in the area
- surface water and groundwater flow in the area
- type of soil and rock
- population density around the proposed plant

After evaluating detailed studies that consider these factors, NRC experts decide whether the proposed site meets their guidelines.

Control room simulator

For safety reasons, proposed nuclea powerplants in the United States must b surrounded by two boundaries. One is th "exclusion area" in the immediate vicinity o the plant. The utility has authority over thi area, and members of the public cannot buil homes or businesses inside this restricte zone. The second boundary marks the "lo population zone," which surrounds th exclusion area in a circle two to three mile from the proposed plant. The outer edge o this zone must be at least one mile from th nearest population center

An area of ten miles surrounding a power -plant is designated as the emergenc evacuation area

Licensin

The NRC (formerly the Atomic Energy Commission) was established in 1974 to regulate the basi functions in the nuclear power industry. Its dutie include licensing, inspection and enforcement standards development, and regulatory research Resident NRC inspectors are assigned to al nuclear powerplants, where they observe an report on plant operations on a day-to-day basis

To receive a construction permit from the NRC a utility must submit an application whic describes the design and location of the propose plant, its safety systems, and its environmenta impact. The utility also prepares a safety analysi report covering such information as site selection choice of materials, equipment design, qualit assurance, and an accident analysis. The detaile analysis verifies that emergency systems ca handle any potential accident without endangering the public

The licensing process also requires a series of public hearings. These hearings give private citizens, community and special interest groups, and state and local officials a chance to express their views about the plant.

Another step in getting a construction license for a nuclear powerplant is a review by an independent organization called the Advisory Committee on Reactor Safeguards (ACRS). The NRC issues or denies a construction permit based on the utility's detailed application and safety analysis reports and the results of the public hearings and ACRS evaluation.

Nuclear Powerplant Emergency Plans

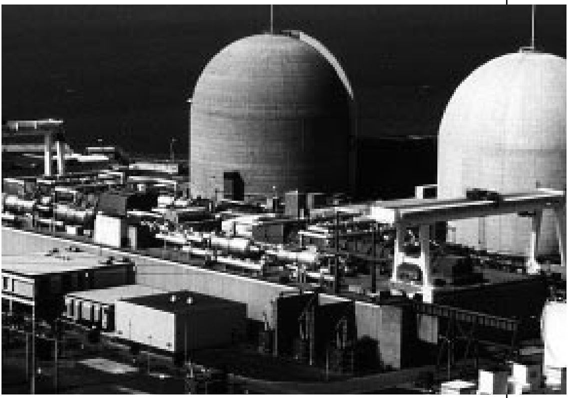
Nuclear powerplants develop extensive plans for warning the public and notifying the authorities within a ten-mile radius in case of any unexpected event that could affect public health and safety. The NRC must approve of the emergency plan before a utility can receive an operating license. As part of the planning, utilities also conduct periodic exercises and drills to ensure that all personnel know what to do in an emergency. These activities are coordinated with other Federal, state, and local agencies.

Nuclear Powerplant Security

Nuclear powerplants maintain strict security to help ensure operating safety and prevent the loss of nuclear materials or acts of sabotage that could cause an unplanned release of radioactive material. The security measures that commercial nuclear powerplants employ include well trained security forces, physical barriers, elaborate electronic surveillance systems, and visitor screening to keep unauthorized persons from entering the site.

Insurance

Every utility that operates a nuclear powerplant must carry insurance to protect the public financially if an accident occurs. Each nuclear plant owner contributes to an insurance pool worth more than $9 billion.



Salem Generating Station Units 1 and 2, located along the Delaware River in Lower Alloways Creek Township, Salem County, N.J.

Current Status of Nuclear Power

Nuclear powerplants currently generate about 20 percent of the electricity in the United States. In the early 1990s, 109 U.S. nuclear reactors had operating licenses. Seven reactors had construction permits, and although some work had been done on all seven, the projects were on hold in 1994. Studies show that those with the highest capacity also have the highest safety ratings and lowest costs.

The Energy Debate

No single energy source can meet all of America's energy needs. The energy debate consists of comparing the advantages and disadvantages of each source and deciding which options best fit with those needs.

Whatever course the nation chooses to follow will require years of planning and commitment—and as future electricity demands are likely to increase, there is little time to lose.

The Department of Energy produces publications to fulfill a statutory mandate to disseminate information to the public on all energy sources and energy conservation technologies. These materials are for public use and do not purport to present an exhaustive treatment of the subject matter.

This is one in a series of publications on nuclear energy.

U.S. Department of Energy

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